Effect of Texture of Polishing Particle on the Surface Roughness of a Cobalt-chromium Alloy Using a Centrifugal Shooting Type Polishing Machine

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In a previous report, we investigated the influence of the shooting angle of polishing particle on the surface roughness of a cobalt-chromium (Co-Cr) alloy using a centrifugal shooting type polishing machine. In the present work, we examined the effects of the texture of polishing particle and polishing time on the surface roughness of Co-Cr alloy cast specimens. Nine different textures of polishing particle were investigated with respect to core material and particle abrasiveness: three different elastic body cores (core A, hard chloroprene rubber; core B, soft chloroprene rubber; core C, natural rubber) and three different green carborundum powders as abrasives (#800, #3000, and #6000). Polishing was performed under a fixed shooting angle of 30° for six different polishing times (1, 2, 3, 5, 7, and 10 minutes). Surface roughness (Ra, Sm) and cutting depth on the polished surface were measured after each polishing stage. Surface roughness was significantly improved within three minutes, particularly using a polishing particle with rough carborundum powder (#800 or #3000) and a heavy core (core A or core B). Cutting depth increased in proportion to polishing time and roughness of carborundum powder, and was least with core C. These results suggested that a polishing particle composed of core B and #3000 carborundum paste was superior for the intermediate polishing of a Co-Cr alloy, and that polishing time should be limited to within three minutes.

Key words: Polishing, Cobalt-chromium alloy, Centrifugal shooting type polishing machine

INTRODUCTION

Although dental alloys are continuously being improved1-9), cast cobalt-chromium (Co-Cr) alloy is widely used for the fabrication of removable dentures. The centrifugal shooting type polishing machine was developed not only to improve the polishing efficiency of Co-Cr alloy with remarkable hardness10-13), but also to prevent dust pollution during polishing14-18). Our previous report demonstrated the usefulness of the centrifugal shooting type polishing machine in the intermediate polishing of cast Co-Cr alloy, producing an excellent surface texture with a shooting angle of 45° or less19). To maximize polishing efficiency using this system, influences stemming from the texture of polishing particle and polishing time should be investigated.

Moreover, fit of the prosthesis to supporting tissues as well as surface roughness should be considered during polishing. Elimination of material from the fitting surface of a metal denture base or retainer by polishing results in reduced retention and stability, making the prosthesis less functional and uncomfortable to wear16,20-22). While it can be difficult to control the amount of elimination with the traditional polishing method using grinding instruments, it is not so with the centrifugal shooting type polishing machine. It enables the texture of the polishing particle, which might affect polishing efficiency, to be changed by selecting the weight and hardness of the elastic rubber core and the roughness of the carborundum layer surrounding the core15,16). Thus, the best polishing condition in terms of both polishing efficiency and fit should be established by controlling the polishing time according to the texture of the polishing particle. To secure the efficiency of the centrifugal shooting type polishing machine, this study investigated the influences of the texture of polishing particle and polishing time on surface roughness, as well as that of cutting depth on the polished surface of cast Co-Cr specimens.

MATERIALS AND METHODS

Polishing system
The centrifugal shooting type polishing machine (Grain-Slider NK, Panasonic Dental Co., Osaka, Japan; Fig.1) used in this study picked up polishing particles from the storage tank using a propeller, and then transported them to the launching device by conveyor belt. The polishing particles were continuously launched from the nozzle of the shooting device using centrifugal force generated by a motor.

The polishing particle consisted of an elastic body core (1-2 mm in diameter) composed of chloroprene rubber and a layer of green carborundum powder as an abrasive (Fig.2). Three types of rubber were selected for the elastic body core to vary weight and hardness: core A was heavy and hard (1.20 g/cm³, International Rubber Hardness
Degree\(^{23}\) = IRHD 90); core B was heavy and soft (1.20 g/cm\(^3\), 65 IRHD); and core C was light and soft (0.92 g/cm\(^3\), 65 IRHD). We selected a green carborundum powder as an abrasive material with sufficient hardness (Knoop hardness 2840 kgf/mm\(^2\)) and low fracture toughness (fracture index 63). Three grades of granularity were used in this study: #800 (ds-50 value of particle diameter 14 \(\mu\)m), #3000 (ds-50 value of particle diameter 4 \(\mu\)m), and #6000 (ds-50 value of particle diameter 2 \(\mu\)m). Polishing particles were then fabricated under nine conditions: three different weights and hardness for the elastic rubber core and three different granularities for the abrasiveness of green carborundum powder.

**Specimen fabrication**
Phosphate-bonded investment blocks were made. To reduce investment porosity, 160 g of powder, 17.5 ml of Heravest M liquid (Heraeus Co., Hanau, Germany), and 7.5 ml of water were mixed for 60 seconds in a vacuum degassing mixer. The mixture was then poured onto a smooth acrylic plate. Two strips of sheet wax (50x20x0.5 mm; KF A, Heraeus Co.) were sandwiched between two investment blocks and buried in the investment. Next, the investment was placed in an electric furnace and heated to a maximum of 1030°C. The Co-Cr alloy (Heraenium EH, Heraeus Co.) was cast into this mold using an induction-heated vacuum pressure casting machine (Comiblabor CL-1 95, Heraeus Co.). After cooling to room temperature, the investment around the casting was removed using a sandblaster (Sandblaster, Shofu Inc., Kyoto, Japan) with a carborundum powder (mean diameter 175 \(\mu\)m) to remove remnants of the investment material and oxide film. This stage was determined as the standard in a polishing operation.

**Polishing using a centrifugal shooting type polishing machine**
In the present study, the shooting angle of polishing particle was set to 30° considering the width of the polishing surface, ease and convenience of the polishing operation, and the results of our previous research — in which an excellent surface texture was produced when the shooting angle was less than 45°\(^{19}\). The specimen was placed in a device in the polishing chamber that controlled the shooting angle, and then shuttled at 1 cm/sec in the same direction as the launched polishing particles. Polishing operation was performed in both directions parallel to the long and short sides of the specimen. Shooting speed of the polishing particle was fixed at 30 m/sec. Polishing time was set to 1, 2, 3, 5, 7, or 10 minutes.

**Measurement and evaluation method of surface roughness and elimination amount**
Surface roughness was evaluated using parameters in conformance to JIS B0601-1994. Centerline average...
roughness (Ra) and mean spacing (Sm) of the specimen surface were measured using a surface roughness measuring apparatus (Surfcom 1400A, Tokyo Seimitsu Co., Tokyo, Japan). For these measurements, the cutoff was 0.8 mm, measurement length (Lm) was 5.0 mm, and measurement speed was 0.3 mm/s. Measurements were made in 15 locations per specimen, as shown in Fig. 3. Each mean value was the average of five specimens.

Amount of elimination by polishing has been previously investigated using two parameters: change in specimen weight before and after polishing, and the cutting depth of the specimen's polished surface. In the present study, we utilized the latter parameter. Before polishing with the centrifugal shooting type polishing machine, specimens intended for elimination amount evaluation were polished by hand using waterproof paper (#120 and #600, Riken Corundum, Kohnosu, Japan) until a flat surface was produced, and then two strips of 7-mm width by the long edges were masked by polyethylene tape. Contour profile of specimen's polished surface was recorded using a surface roughness measuring apparatus in which the cutoff was 0.8 mm, measurement length (Lm) was 8.0 mm, and measurement speed was 0.3 mm/s. Measurements were made in five locations per specimen, as shown in Fig. 4. On the recorded contour profile, cutting depth was employed as the parameter that measured the amount of elimination, as shown in Fig. 5. Each mean value was the average of five specimens.

To examine the differences in Ra, Sm, and cutting depth between nine different textures of polishing particle at each polishing time, data were analyzed using one-way ANOVA followed by a multiple comparison test. Statistical significance was established at p<0.05 level.

**RESULTS**

Ra, Sm, and cutting depth for the respective polishing particles at each polishing time are shown in Fig. 6, where the temporary change in each parameter could be evaluated. Ra decreased drastically during the first minute, reaching a plateau within 3-5 minutes for each type of polishing particle. We therefore compared each parameter among the nine different polishing particle textures at three minutes of the polishing time.

When comparing Ra at three minutes of the polishing time between abrasives (Fig. 7A), the finer the abrasive the larger Ra tended to become, and there were significant differences in Ra between #800A (combination of #800 abrasive and core A) and #6000A (p<0.01), and between #3000A and #6000A (p<0.05). When comparing Ra at three minutes of the polishing time between cores (Fig. 7B), Ra was significantly larger for core C than for cores A and B (#800, #6000: p<0.01; #3000: p<0.05). No differences were found between core A and core B with each abrasive.

On the other hand, temporary change in Sm was kept up during the polishing operation and the state of increase in Sm varied according to the texture of polishing particle. When comparing Sm at three minutes of the polishing time between abrasives (Fig.
8A), the finer the abrasive, the smaller Sm tended to become, with significant differences between #3000 and #6000 for each core (cores A and B: p<0.01; core C: p<0.05) and between #800 and #6000 for cores B and C (p<0.01). There were no significant differences in Sm between cores with each abrasive (Fig. 8B).

Cutting depth increased almost in proportion to polishing time (r=0.97-0.98 in Pearson correlation coefficient). When comparing cutting depth at three minutes of the polishing time between abrasives (Fig. 9A), the finer the abrasive, the smaller the cutting depth tended to become, with significant differences in cutting depth between #800 and #3000, between #800 and #6000, and between #3000 and #6000 (p<0.01). When comparing cutting depth at three minutes of the polishing time between cores (Fig. 9B), cutting depth using core A was significantly larger than that using cores B (#800 and #6000: p<0.01; #3000: p<0.05) and C (p<0.01), with the
Fig. 7 Comparisons of surface roughness (Ra) for each type of polishing particle with respect to core and abrasive at three minutes of polishing time. Comparison between abrasives is shown in A and that between cores is shown in B.

Fig. 8 Comparisons of surface roughness (Sm) for each type of polishing particle with respect to core and abrasive at three minutes of polishing time. Comparison between abrasives is shown in A and that between cores is shown in B.

Fig. 9 Comparisons of cutting depth for each type of polishing particle with respect to core and abrasive at three minutes of polishing time. Comparison between abrasives is shown in A and that between cores is shown in B.
cutting depth produced by core B larger than that produced by core C (#800: p<0.01; #6000: p<0.05).

**DISCUSSION**

In this study, we investigated the effect of the texture of polishing particle in a centrifugal shooting type polishing machine on the surface roughness of cast Co-Cr alloy using nine different polishing particles textures (three types of core and three types of abrasive). Temporary changes in Ra and Sm suggested that the surface texture of the polished surface of Co-Cr alloy was considerably improved within three minutes by this type of polishing machine.

We demonstrated that heavy cores (cores A and B: 1.2 g/cm³) were more effective than the lighter core (core C: 0.92 g/cm³) from the standpoint of polishing efficiency within a three-minute period. Since the polishing particles were launched from a nozzle of the shooting device using centrifugal force generated by a motor in this type of polishing machine, the weight and hardness of the core might influence energy and rebound upon collision with the polished surface. A heavy core would produce a deep cutting depth and long sliding distance on the polished surface, and both of which contributed to polishing efficiency.

We also demonstrated that rough abrasives (#800 and #3000) were more effective than the finest abrasive used (#6000) with regard to polishing efficiency over a three-minute duration. For each core type, texture of the polished surface was improved within a short polishing time when using rough abrasives (#800 and #3000) compared to using the finest abrasive (#6000). We attributed this finding to an increase in cutting depth on the polished surface when using a polishing particle with a low-granularity abrasive.

Although use of a high-granularity abrasive was reported to produce a finely textured polished surface⁴⁰, superiority of an abrasive with high granularity (#6000) with respect to surface roughness could not be confirmed by extending polishing time to 10 minutes in the present study. It is therefore suggested that when using centrifugal shooting type polishing machine, it is desirable to use polishing particles consisting of a heavy core coupled with a rough abrasive to achieve good polishing efficiency within a limited polishing time.

Cutting depth, however, should also be considered when searching for the best combination of core and abrasive among the nine different textures of polishing particles used in the present study. An increase in cutting depth in proportion to polishing time suggested that unnecessary extension of polishing time should be avoided so as to maintain prosthesis fit. We also found that cutting depth was lower when using polishing particles with a fine abrasive and with a light, soft core. These findings suggested that to obtain a surface texture sufficiently improved for the intermediate stage of polishing cast Co-Cr alloy, a polishing particle consisting of a heavy and soft core with a medium-fine abrasive (#3000B) would be the most suitable as this combination also helped to maintain prosthesis fit. In this condition, cutting depth on the polished surface over a three-minute duration was 12.7 μm using the centrifugal shooting type polishing system, a depth which is considerably smaller than that achieved by sandblasting⁴⁰.

**CONCLUSIONS**

The most suitable polishing particle composition and polishing time for the intermediate stage of polishing a Co-Cr alloy using the centrifugal shooting type polishing machine was clarified. These findings should prove useful for improving polishing efficiency and the polishing environment during the fabrication of metal plate dentures.

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